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REVIEW ARTICLE

Bioefficacy of indigenous plant products against pests and diseases of Indian forest trees: A review

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Abstract: This review discusses the bioefficacy of natural products (derived from neem and other tropical trees) which have been used against insect pests and diseases attacking forest trees in India. These products are effective, cheaper and eco-friendly and act as antifeedant, repellent, sterility inducing, toxic or regulate insect growth. Integration of these products in forest pest management strategies would enhance the sustainability of forests and prevent the deterioration of wood quality.

Keywords: Indian forests, Pests and diseases, Plant products, IPM, Perspective

Introduction

Forest trees are renewable sources as these yield quality wood and other products, and are a means of maintaining biodiversity. Also, these species are sources of medicines, food and timber, and biomass. There is therefore an increasing global demand for forest products and forests as ecosystem service providers. Large scale deforestation is diminishing. However, droughts, pests and diseases reduce productivity and deteriorate wood quality. Common trees in tropical and temperate zones are listed in Table 1.

During the era of global warming and carbon credit, forest productivity is critical. Forest productivity can be increased by reducing levels of pest populations and disease pathogens and tree damage. Applications of chemical pesticides help save the forests and their production. This, however, is not eco-friendly and environment-safe as toxic pesticides threaten biodiversity and environment, and induces genetic pollution including development of pesticide-resistant pests. Also, synthetic pesticides kill friendly insects, pathogens and micro-organisms. Therefore, use of eco-friendly pesticides is a focal point in social forestry where plant-derived pesticides may be effective means.

Neem (*Azadirachta indica*) as source of allelochemicals has been used for large-scale management of pests (Sidhu 1995; Gahukar 1995) and plant diseases (Mariappan 1998). At present, over 50 ready-to-use products are available in the market in the form of emulsifiable concentrate containing 0.03–0.15% of azadirachtin (AZ) as main bioactive constituent (Gahukar 1998). Neem-coated urea and neem cake (NC) are other products. Neem products control insects and mites as these act as antifeedant, sterilant, oviposition deterrent, insect growth regulator (IGR) and contact poison. Neem products also inhibit and retard growth of bacteria and fungi. Since vectors of viruses are controlled, the infectivity of viral diseases is considerably reduced (Gahukar 1995).

Traditional preparations are common in tribal/rural areas, such as, neem seed kernel extract (NSKE), neem seed extract (NSE), neem leaf extract (NLE), neem leaf powder (NLP) and neem seed/kernel oil (NO). The water extract (5%) or NO (2%−3%) is mixed with water, soap water as spreader is added and whole mixture sprayed at 500L/ha with knap-sack sprayer. Farmers prepare the spray liquid without any technical know-how and financial help. In this paper, I review literature on utilization of plant products in protection of forest trees aimed at making the people aware of the potential of plant-based traditional preparations and commercial formulations.

Current status of pests and diseases of forest trees

Although about 60 pests and 70 plant diseases attack forest trees, their damage potential and economic importance has not been studied in detail, and the current status of each pest species and disease is known only for certain areas (Nair 2007). In recent years, there had been frequent pest outbreaks and disease epidemics in forest zones where colossal losses have been reported (FAO 2005). Also, Paine (2009) pointed out that the complex of pests and diseases associated with forest trees is fast changing mainly due to climate change and instability in natural habitats.

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Some exotic species were introduced and pests shifted their preference of host plants (FAO 2005). For example, a shoot and root borer, *Celosterna scabrator* F. infesting acacia (*Acacia nilotica*) became a serious pest of eucalyptus (*Eucalyptus* sp.) in Uttar Pradesh, Andhra Pradesh and Madhya Pradesh. A major pest of apple plantation and mulberry (*Morus* spp.) fields has adapted to poplar (*Populus* spp.) as its host. Also, the monoculture of forest trees is highly vulnerable to insects compared to virgin forests or forest with wide biodiversity. For example, in southern states and recently in Chhatisgarh and Madhya Pradesh, two defoliators, *Hyblaea puera* Cramer and *Eutectona* (*Hapalia*) *macheralis* (Wlk.), and the trunk borer, *Hoplocerambyx spinicornis* Newman have devastated teak (*Tectona grandis*) plantations; another defoliator, *Eligma narcissus* Cramer and webworm, *Atteva fabriciella* Swed. destroy trees of *Ailanthus excelsa* and *A. malabarica* in south India; the shoot borer, *Tonica niviferana* Wlk. destroys *Bombax malabarium* plantations in Bihar and West Bengal; popular trees in Himachal Pradesh are defoliated regularly by *Pygaera cupreata* Butl. and *Pygaera fulgurita* F.

Table 1: Indian forest trees studied for pest and disease management.

Botanical name	Local/English name
Acacia catechu Willd.	Khair
Acacia nilotica (Lamk.) Willd.	Prickly acacia, babhul
Aegle marmelos Correa	Bael
Albizzia lebbeck Benth.	Siris, lebbeck
Azadirachta indica (A. Juss.)	Neem
Bambusa bambos (L.) Voss	Bamboo
Bauhinia variegata L.	Bauhinia, mountain ebony
Butea frondosa Roxb. Ex Willd.	Palas, flame of the forest
Cassia fistula L.	Cassia
Cassia siamea Lamk.	Kassod tree
Casuarina equisetifolia L.	Casuarina
Dalbergia sissoo Roxb.	Shisham, Indian rose wood
Eugenia jambos L.	Blue berry, jamun, rose apple
Ficus benghalensis L.	Banyan
Ficus religiosa L.	Peepal, sacred fig
Hardwickia binata Roxb.	Anjan
Jatropha curcas L.	Jatropha, wild castor
Koelreuteria paniculata Laxm.	Golden raintree, pride of India
Leucaena leucocephala (Lam.) de Witt	Shubabhul, leucaena
Litsaea polyantha A. Juss.	Soalu
Madhuca indica Gmel.	Mahua
Melia azaderach L.	Melia, bakain, China berry
Michelia champaka L.	Champa, champaka
Morinda tinctoria Roxb.	Nuna, Indian mulberry
Moringa oleifera Lam.	Moringa, drumstick
Morus alba L., *M. indica* L.	Mulberry
Persea/Machilus bombycina (King ex Hook)	Som
Pongamia pinnata (L.) Pierre	Karanj, pongam
Populus spp.	Poplar
Prosopis cineraria (L.) Druce	Khejri, jandi
Salvia aegyptiaca L.	Salvia, sage
Salvia divinorum Epling & Jativa	Magic mint, salvia, sage
Shorea robusta Gaertn.	Sal
Swietenia mahogoni Lamk.	East Indian mahogany
Tabernaemontana spp.	East Indian rosebay
Tamarindus indica L.	Tamarind
Tectona grandis L.	Teak

There is challenge of new pests also which may cause serious plant damage under favourable conditions and pest resurgence occurs due to adaptation to local microclimate. Under such altered conditions, insects multiply to amazing and unmanageable levels on account of their high reproductive potential, short life cycle and continued availability of hosts. These pests reported during last decade include: mealybug, *Pseudococcus gilbertensis* (Beards.); scale, *Partaloria orientalis* Rao, eryiophyid mite, *Calipitrimerus azadirachtae* Channabasavanna (Karthikeyan et al. 1997, 1998), and curculionid weevil, *Myllocerus laetivirens* Marshall on neem tree (Seemakumar et al. 1997); the shoot webber, *Nephoteryx eugraphella* Ragnot on jatropha (*Jatropha curcas*) (Ambika et al. 2007).

Testing of plant products

Among indigenous plants, 31 species belonging to 23 families referred in this paper have been tested either in laboratory or field for their bioefficacy against pests and pathogens that attack forest trees (Table 2). These plants were selected for testing because they have been used in Ayurvedic or Unani medicines for human health or their bioefficacy has been proved on pests of agricultural crops.

Preparation of plant extract:

Plant parts are collected, dried in shade, and crushed into pieces using pestle and mortar. For water extract, these pieces are soaked overnight in clean water and filtered through clean cloth. By adding required water, desired concentration is obtained. The same procedure is followed for cake extract. Alcoholic extracts are prepared following the procedure of refluxing. The filtered extract is concentrated by distillation process. For fractionation, alcohol extract is mixed with silica gel (column chromatography) for drying and hexane is poured. The filtrate is collected and distilled to obtain concentrated hexane fraction. The same procedure is followed using chloroform and then acetone or other organic solvent to obtain the respective fractions.

Laboratory bioassay

Different techniques are used to apply pesticide such as, topical application, leaf disc technique, incorporation of plant product in artificial diets and direct dip bioassay. Insect mortality, oviposition, fecundity, growth parameters, deformity in life stages, mortality etc. are observed and compared. In case of disease pathogens, soil is inoculated or treated seeds are sown. Observations on spore germination, mycelial growth, seedling emergence and growth vigour are taken.

Field trial

Cake is incorporated into soil and thoroughly mixed. Trees are sprayed with knap-sack sprayer with given concentration of plant product. Data on plant damage, insect population level, development of insect stages and mortality in case of insects and inci-

dence of diseases and nematodes are used for comparison.

Table 2. Plant species used in pest and disease management in Indian forests.

Plant species	Family	Common name	Plant habit
Adhatoda vasica Nees	Acanthaceae	Malabar nut	Evergreen shrub
Adhatoda zeyanica L.	Acanthaceae	Malabar nut	Evergreen shrub
Aloe graminicola L.	Liliaceae	Aloe	Stoloniferous succulent shrub/ornamental
Anacardium occidentale L.	Anacardiaceae	Cashew	Small evergreen tree
Argemone mexicana L.	Papaveraceae	Mexican poppy	Prickly herb/undershrub
Azadirachta indica A. Juss.	Meliaceae	Neem	Common roadside tree
Calotropis gigantea (Ait)	Asclepiadaceae	Madar	Perennial undershrub
Calotropis procera (Willd.)	Asclepiadaceae	Swallow wart	Tall evergreen shrub
Cassia siamea Lamk.	Caesalpiniaceae	Kassod tree	Ornamental/avenue tree
Celosia argentea L.	Amarathaceae	Cock's comb	Common seasonal/annual weed
Citrus aurantifolia (Christm.)	Rutaceae	Lime	Cultivated tree
Datura metel L.	Solanaceae	Thorn apple	Wild seasonal undershrub
Dirca pallustris L.	Thymelaeaceae	Dirca	Shrub with ornamental bark
Dirca sp.	Thymelaeaceae	Dirca	Hard deciduous shrub
Eucalyptus sp.	Myrtaceae	Eucalyptus	Tall ornamental tree
Eupatorium odoratum L.	Compositae	Siam/devil weed	Small aromatic undershrub
Euphorbia tirucalli L.	Euphorbiaceae	Milk bush	Succulent spineless tree
Ipomoea hederacea Clarke	Convolvulaceae	Star ipomoea, morning glory	Perennial spreading shrub/weed
Launaea coromandelica (Houtt.) Merrill	Asteraceae	Launaea	Biennial or perennial creeper
Lippia javanica Burm.	Verbenaceae	Lemon bush	Aromatic shrub
Melia azedarach L.	Meliaceae	Drek	Small tree/hedge plant
Murraya koenigii (L.) Spreng.	Rutaceae	Curry leaf tree	Small tree with flavouring leaves
Ocimum spp.	Labiatae	Basil	Sacred small perennial plant
Oxalis corniculata L.	Oxalidaceae	Wood sorrel	Small annual/perennial herb
Parthenium hysterophorus L.	Euphorbiaceae	Carrot weed, rag weed	Tall perennial shrub/weed
Parthenium sp.	Euphorbiaceae	Parthenium	Tall perennial shrub/weed
Polygonum sp.	Polygonaceae	Buck wheat, knot weed	Perennial herb
Pongamia pinnata (L.) Pierre	Papilionaceae	Pongam	Perennial large tree
Ricinus communis L.	Euphorbiaceae	Castor	Small cultivated herbaceous shrub
Sesbania sp.	Leguminosae	Sesbania	Tall soft shrub
Vitex negundo L.	Verbenaceae	Chaste tree	Shrub/small tree in wasteland

Bioefficacy of plant products

The bioactive constituents (allelochemicals) and their mode of action differ from one plant species to another (Table 3). Since all allelochemicals in conventional preparations have not been often isolated and identified, the major ones are mentioned.

Insects

Coleoptera: The seed beetle, *Caryodon serratus* Olivier (Bruchidae) is considered as major pest of acacia and tamarind (*Tamarindus indica*). The grub feeds voraciously on developing seeds and significant loss in weight and deterioration in quality occurs. In the laboratory, when seeds were treated with neem product FortuneAza® containing 0.0075%–0.015% of AZ and adults were released, the product acted as ovipositional deterrent (Murugesan et al. 1998 a). With leaf powder of neem, *Ocimum* sp., *Sesbania* sp. and *Parthenium* sp. used for seed treatment at $2g\cdot kg^{-1}$ seed; in the laboratory, all adults were found dead within 12 h (Murugesan et al. 1998 b). Spraying of 5% extract of *Vitex negundo* leaves resulted in 100% pest mortality on sixth day, reduced fecundity by 35%, and adult emergence and survival rate was negligible.With 1g pellets of neem or *V. negundo*, beetles were deterred from feeding (antifeeding effect). All these treatments were as effective as synthetic pesticides (Murugesan et al. 2000).

Homoptera: A whitefly species, *Acaudaleyrodes rachipora* (Singh) (Aleyrodidae) is a regular pest of acacia. Adults and nymphs suck sap from leaves that become yellowish and wither. In social forestry trial, Sundararaj (1999) could significantly kill the eggs and nymphs on a month-old seedlings by incorporating neem cake into soil ($50\ kg\cdot ha^{-1}$) after mixing it with Vesicular arbiscular mycorrhiza and rhizobium culture at $1g\cdot kg^{-1}$ soil whereas a mixture of NO (0.5%) + endosulfan 35EC (0.1%) or monocrotophos 36SL (0.05%) alone was found ineffective (Sundararaj 1997). In earlier trials, neem oil (0.5%) was significantly superior in bioefficacy than these synthetic insecticides (Sundararaj et al. 1995).

Adult populations of another whitefly, *Trialeurodes vaporariorum* (Westwood) (Aleyrodidae) attacking salvia (*Salvia* spp.) were reduced up to 16%–40% from 100% by spraying Neemgold® (0.15% AZ) or vegetable oil (3%) and up to 27% by imidacloprid 200SL (0.0097%) followed by water suspension of entomofungus, *Beauveria bassiana* Vuill. (7.5×10^{-6} $cfu\cdot mL^{-1}$) (Sood et al. 2003).

Dubey and Sundararaj (2004) evaluated six commercial neem products, neem oil and synthetic pesticide against *Aleurodicus dispersus* Russell (Aleyrodidae) on champa (*Michelia champaka*) and bauhinia (*Bauhinia variegata*). When number of

nymphs/leaf was counted 31 days after treatment, lowest population density (33–49 nymphs) was noted on trees sprayed with ParaAza® (0.03% AZ) at 5 mL·L^{-1} followed by Nimbecidine® (0.03% AZ) at 1 mL·L^{-1} and chlorpyriphos 20EC (2 mL·L^{-1}) with 38–54 nymphs against control (69–107 nymphs/leaf).

A psyllid, *Heteropsyalla cubana* (Crawford) (Psyllidae) infests subabhul (*Leucaena leucocephala*) and sucks sap from the shoots and leaves that wither and dry. Spraying trees with NO (3%) was the best treatment against all stages of this pest (Sharma et al. 1992).

Table 3. Allelochemicals (Bioactive constituents in plant species) and their mode of action on insect pests and disease pathogens attacking Indian forest trees.

Plant species	Part (product) used	Major allelochemical	Mode of action
Adhatoda vasica	Leaf (AE, WE)	Alkaloids (vasicine, vasicinone)	PE
Adhatoda zeyanica	Leaf (WE)	Alkaloids (vasicine, vasicinone)	FU
Aloe graminicola	Leaf (dried)	Malonylnataloin	PE
Anacardium occidentale.	Nut (shell liquid)	Alkyl phenols, flavonoids	PE
Argemone mexicana	Plant (dried)	Alkaloids (protopine, berberine)	PE
Azadirachta indica	Leaf, kernel, (AE, WE, oil, cake, pellet)*	Triterpenes (nimbin, azadirachtin, nimbecidine	AF, IGR. OD, PE, RE
Calotropis gigantea	Leaf (WE)	Oligoglycosides, calotropeal, triterpenes	FU
Calotropis procera	Leaf (WE)	Oligoglycosides, calotropeal triterpenes	FU, PE
Cassia siamea Lamk.	Leaf (mulching)	Arthraquinone, phylobatannins isoquinolone alkaloids	RE
Celosia argentea.	Leaf (WE)	Triterpenoid saponins, flavonoids	FU
Citrus aurantifolia	Leaf (juice)	Sisquiterpenes hydrocarbons/alcohol	RE
Datura metel.	Flower, seed (AE, WE)	Atropine alkaloids, diterpenes, megastigmane sesquiterpenes	PE
Dirca pallustris	Seed (ACE)	Diterpenes (tiglianes, daphnanes, i-alkyldaphanes	AF
Dirca sp.	Seed (ACE)	Diterpenes	AF
Eucalyptus sp.	Leaf (WE)	Eucalyptol, citronellol, aromadendrene, linalool, citral, rutin, tannins, terpineol	FU
Eupatorium odoratum	Leaf, flower (WE)	Pyrrolizidine alkaloids, flavonoids, terpenoid hydrocarbons	FU
Euphorbia tirucalli	Branch, flower(WE, wood ash)	Triterpenes, diterpene esters, steroids	RE
Ipomoea hederacea Clarke	Seed (WE)	Triterpenoids, ecdysteroids, steroidal glycosides	IGR
Launaea coromandelica	Leaf	Not known	FU
Lippia javanica Burm.	Leaf (dried)	Terpenoids, piperitenone	PE
Melia azedarach L.	Leaf, kernel (ACE, WE)	Triterpenoids, flavonoids, limonoids, tannins, glycosides, hydroxyl coumarin	OD, PE
Murraya koenigii.	Leaf (WE, dried)	Carbazol alkaloids, carbazoloquinone, sesquiterpenoids, monterpenoids	PE
Ocimum spp.	Leaf (dried)	Oxygenated/hydrocarbon monoterpenes, sesquiterpenes	PE
Oxalis corniculata.	Leaf (WE)	C-glycosylflavones, oxalic acid	FU
Parthenium hysterophorus.	Leaf (WE, dried)	Sesquiterpne lactone (Parthenin), dampsin, phenolics	FU, PE
Parthenium sp.	Leaf (dried)	Sesquiterpne lactone (Parthenin), dampsin, phenolics	FU, PE
Polygonum sp.	Leaf (WE)	Catechi, oxalic acid, gallic acid, glucopyranoside	PE
Pongamia pinnata (L.) Pierre	Seed (AE, WE)	Pongagobol, globone, pongine, karanjin, pongapin, pongapinone	FU, NEM, PE
Ricinus communis	Leaf, seed (AE, oil, cake)	Glycoprotein (ricin), polyurethane, lectin	PE, RE
Sesbania sp.	Whole plant (dried)	Sesbanimide, saponin, tannin, phenolic compounds	PE
Vitex negundo.	Leaf (WE, pellet)	Norditerpene alkaloids, monterpenes, flavonoids, sabinene, linalool	AF, OD, PE

ACE= alcoholic extract, AE= aquous extract, AF= antifeedant, FU= fungicidal, IGR=insect growth regulator, NEM= nematicidal, OD= oviposition deterrent, OV= ovicidal, PE= pesticidal, RE= repellent. WE= water extract. *Commercial/patented products from neem: Achook, Fortune-AZ, NeemAzal, Neemark, Neemgold, Nimbecidine, Para-AZA

Isoptera: Several species of termites (Rhinotermitidae, Termitidae) attack roots and plant base of all most all forest trees, thereby affecting plant development. Affected trees wither and die. Even germinating seeds and grown up trees can be damaged. Both soil-inhabiting (subterranean, mound building) and wood-inhabiting (damp/dry wood) species are found in forest ecosystems, the common genera are: *Reticulitermes, Odontotermes, Kalotermes* and *Heterotermes*. Following plant products have been tested with varied results of pest control, viz. latex of *Calotropis procera* (Giridhar et al. 1988), dried plant of *Argemone mexicana* (Ghosh and Duary 2000), NO, oil or cake of *Ricinus communis* (Sharma et al. 1990), shell liquid of *Anacardium occidentale* (Jain et al. 1989), leaves of *Murraya koenigii* (Pathak et al. 2000), water extract of woodash or leaves of *Euphorbia tirucalli*, leaves or berries of neem, *Melia azaderach,* leaves of *Lippia javanica, Ocimum* spp., *Aloe germinicola* (Lakshmanan 2002). These treatments were made either by putting/pouring the product into holes while planting trees or after digging mounds.

The juice of *Citrus aurantifolia* and cake of *Ricinus communis* mixed with water showed antifeeding action whereas mulching with leaves of neem or *Cassia siamea* could prevent termites to enter into ground (Lakshmanan 2002). These treatments however, could have been compared with synthetic pesticides (chlorpyriphos, lindane) that are routinely used in termite control in forests.

Lepidoptera: The silkworm, *Bombyx mori* L. (Bombylidae) is reared on leaves of mulberry, soalu (*Litsaea polyanthus*) and som

(*Persea bombycina*). Plant products are beneficial in this rearing by two ways, e.g. (1) improving cocoon yield and (2) controlling the parasitoid of silkworm. In the laboratory, Bohidar and Choubey (2005) administered water extract (25 mg in 50 mL) of 18 Indian plants at 1.5 mL/larva and noted an increase in weight of larva, shell and cocoon and shell ratio. When water extract of *Ipomoea hederacea* seed containing 15% of crude resinous matter made up of glycosidal and non-glycosidal fractions was applied to larvae, it acted as moulting hormone (pharbitoin) and facilitated metamorphosis (Ghosh et al. 2004). This effect was similar to that of ecdysone and proved useful in silkworm rearing. Therefore, how to use this bioactive constituent for commercial purpose is a matter of further studies.

The tasar silkworm, *Antheraea mylitta* Drury (Saturniidae) larvae are attacked by a dipterous parasitoid/an uzi fly, *Blepharipa zebina* Wlk. (Tachinidae) and silkworms die within a week. When a neem-based product Achook® (0.015% AZ) at 0.02%–4% was bioassayed in the laboratory to study its effects on growth and development of parasitioid's maggot, prepupa and pupa, the product acted in a dose-dependent manner and resulted in larval-pupal intermediates, small-sized flies with morphological abnormalities, reduced maggot weight, and prolonged pupation (Singh and Thangavelu 1996). These trials may be extended since there is great scope for plant products to be used for parasitoid control.

Deilephila sp. (Sphingidae) is a sphinx moth. Young larvae feed in groups on leaves of East Indian rosebay (*Swietenia mahagoni*). During later stages, larvae move individually and complete defoliation occurs due to their feeding. Spraying with Nimbecidine® (2mL·L^{-1}) produced up to 88% deformed moths and killed 90% of larvae (Ramarethinam et al. 2002 a).

The reddish larva of the borer, *Zeuzera indica* Helf. (Cossidae) bores into stem and branches of som and soalu and feeds on internal tissues. It forms the net by extracting silky thread. The larva tunnels down entering the main stem and reaching up to the main root in young plants that are completely killed. The heavily attacked parts dry in a few days and borer holes on the stem are apparent. Cotton swab soaked in 100% aqueous extract of neem, *Pongamia pinnata, Ricinus communis, Datura metel* or *Adhatoda vasica,* was inserted into borer hole and closed with mud plaster. This simple method resulted in up to 95% of the borer mortality (Sahu et al. 2008).

The stout cylindrical brownish green larva of the leaf roller, *Hyblaea puera* (Hyblaeidae) is major pest of teak. Trees are often found with skeletonized leaves because larva feeds on green matter leaving only ribs. In laboratory, alcoholic extract and fractions of *Dirca palustris* seeds at 5% acted as antifeedant and reduced food consumption index and nutritional parameters due to feeding deterrency (Murugesan 2001).

The shisham tree (*Dalbergia sisoo*) is often attacked by a leaf feeder pest, *Plecoptera reflexa* Guen. (Noctuidae). Larva eats away the young shoots and leaves. When trees were sprayed with neem product Neemark® (0.015% AZ) applied at 5 ml·L^{-1}, there was significantly greater larval mortality than sprays of endosulfan 35EC (0.07%), malathion 50EC (0.05) or methyl parathion 50EC (0.05%) (Jemla Naik et al. 1995). Another defoliator pest is *Rhesala imperata* Wlk. (Noctuidae). Larva eats voraciously the leaves of lebbeck (*Albizzia lebback*) trees. The pest was effectively controlled with sprays of alkaloids extracted from leaves of *Adatoda vasica* or *Polygonum* sp. (Bhargava et al. 1997) or seeds of *Datura metel* (Kulkarni and Joshi 1997). Laboratory trial on common defoliator, *Plecoptera cupreata* (Notodontidae) showed that different fractions of extracts of *Melia azedarach* kernel act as oviposition deterrent and are useful in reducing egg numbers (Bhandari et al. 1988).

Two grass yellow butterflies (Pieridae): *Eurema hecabe* (L.) on falcata (*Paraseranthes falcataree*) and *Eurema blada* L. on cassia (*Cassia fistula*) are regular pests. Larva of all ages feeds on leaves voraciously and defoliates the trees which affect tree growth and development. A neem product, Nimbecidine® alone (6 mL·L^{-1}) or a mixture of Nimbecidine (2 mL·L^{-1}) and quinalphos 25EC (1 mL·L^{-1}) gave tree protection to the extent of 83.6% and resulted in deterrency in larval feeding (60%), and adult oviposition (44%); however, maximum deformed adults (88%) were produced with Nimbecidine only at higher doses (Ramarethinam et al. 2002 b). The histopathology of digestive system of mature larva studied earlier was confirmed by these observations (Ramarethinam et al. 2005).

Other important pests of forest trees belong to family Pyralidae; viz. *Eurema macheralis* on teak; *Macalla thyrsisalis* Wlk. on mahogany (*Swietenia mahogoni*); *Nephropteryx eugraphella* Ragnot and *Pempelia morosalis* (Saalm Uller) on jatropha. Young shoots and leaves are eaten up by larvae and plant growth is considerably retarded. Recently, Ambika et al. (2007) reported 92% of mortality of *P. morosalis* larvae with NO (2%) whereas other neem crude products: NC water extract (10%), NSKE (10%), and NeemAzal® (0.002%) were found ineffective. The maximum mortality of 98% was however obtained with *Bacillus thuringiensis* at 10 g·L^{-1}. In laboratory trial, alcoholic extract of *Dirca palustris* seeds has been reported as antifeedant to *E. macheralis* larvae (Murugesan 2001).

Pathogens:

The saphrophytic fungus, *Aspergillus* spp., infects neem seeds stored in humid weather and infected seeds rot. The rotting could be prevented by sprays of water extract (5%) of *Pongamia pinnata* seeds or NO (2%) (Srivastava et al. 1997).

Powdery mildew caused by fungus, *Phyllactinia corylea* (Pers.), leaf spots by *Aecidium (Peridiospora) mori* Syd. & Butl., and leaf rust caused by fungus, *Cerotelium fici* (Cast), are common diseases on mulberry leaves. The disease infection was reduced by >50% after spraying plants with 10% alcoholic/ water extract of neem, *Adhatoda zeylanica*, *Launaea coromandelica, Oxalis corniculata, Celosia argentea* or *Eupatorium odoratum;* among them, extract of *A. zeylanica* was most effective (Biswas et al. 1995). Similarly, the mycelial growth of three fungi, viz. *Fusarium pallidoroseum* (Cooke) Sacc., *Fusarium moniliforme* var. *intermedium* Neish & Legget and *Fusarium oxysporium* Schelcht, was inhibited up to78%–84% in the laboratory, and the disease incidence in greenhouse was reduced by 63%–67% by spraying water extract (5%) of neem, *Pongamia pinnata*, *Calotropis gigantea*, *Eucalyptus* sp. or *Parthenium hysterophorus* (Gupta et al. 1996).

Nematodes:

Root knot nematodes are known to attack forest trees. The juveniles penetrate ino roots and galls are formed which block flow of plant nutrients to above ground plant parts. This arrest in effect, causes significant reduction in plant growth and wood production. In mulberry, two species: *Meloidogyne incognita* Sandground, *Hoplolaimus indicus* Sher, could be managed by three ways: (1) incorporation of neem cake into soil every year at 2 $t{\cdot}ha^{-1}$ in four doses at an interval of three months. (2) mulching of green leaves of neem or *Pongamia pinnata* at 2.55 $t{\cdot}ha^{-1}$, (3) talc-based bionematicide Bionema® produced by beneficial nematophagous fungus, *Verticillium chlamydosporium* Goddard applied at 80 $kg{\cdot}ha^{-1}$ after mixing it with FYM (20 $t{\cdot}ha^{-1}$) and NC (2 $t{\cdot}ha^{-1}$) (Singh 2009).

Future needs

(1) Inventory of forest trees in each ecosystem is fragmentary or not easily available. Compilation of information is needed. Also, efforts can be initiated for minimizing genetic depletion of forest genotypes/ecotypes and for conserving biodiversity. Habitat management for conservation of natural enemies of insect pests would be another aspect of research. The community participation may therefore be strengthened for large scale afforestation and conservation of forest trees that are used for human welfare.

(2) Many forest trees possess pesticidal property. However, some trees are victims of pests and diseases. For example, neem tree suffers from the attack of at least 14 pests and nine diseases (Gahukar 1995). Can plant products be used against them? Of course, difficulty in treating tall tress by ground equipments is generally experienced in the developing and less-developed countries. Can large scale spraying be advantageous economically?

(3) Plant diseases of forest trees and their management based on ecology have received little attention of researchers and extension agencies. For example, soil application of neem cake and neem-coated urea has been advocated for horticultural crops (Akhtar, 2000) and the same treatment may hold true in social forestry?

(4) Chemical pesticides are easily available in villages and towns whereas plant-based products are difficult to get. Farmers also do not show their interest in plant products due to huge publicity of chemical pesticides, incentive by companies, subsidy by government, lack of technical information etc. Awareness campaigns with the help of NGOs and public organizations can convince foresters of the economic and ecological advantages of plant products.

(5) Early detection systems for plant damage and facilities for identification of insects and pathogens are inexistent in India. Establishment of plant clinics would certainly help to plan spraying operations particularly those ones that are recommended for prophylactic treatments.

(6) Traditional preparations based on indigenous plants are used for spraying. But sprays are washed off plants due to heavy rains. Also, crude preparations are sensitive to high temperatures and break down easily due to UV light (Gahukar 1998). Frequent applications are therefore required to achieve satisfactory plant protection. This practice increases the cost. How to improve the residual toxicity of these preparations is a subject of intensive research. Meanwhile, local cheap stickers (gum *arabic*, unrefined/brown sugar, soap water etc.), stabilizers and anti-oxidants which are cost-effective may be experimented.

(7) Neem has been extensively used for conventional preparations and commercial formulated products. Other indigenous plants, though abundant, are yet to be studied for such exploitation (Suresh et al. 2001). For example, *Acorus calamus, Annona squamosa, Datura stramonium, Lantana camara, Madhuca indica, Tagetes* spp., *Tridax procumbens, Tabornaemontana coronaria, Tephrosia* sp., *Celastrus angustatus* etc. The interest in this experimentation is lacking probably because of lengthy and costly process of synthesis and formulation. Further, verification of cost of treatment and effectiveness against pests and diseases of forest trees may be necessary before these products are promoted in forestry.

(8) Content of biologically active constituents in plants such as, AZ (Senguttuvan et al. 2005), nimbin and salanin (Sidhu et al. 2004) in neem, differs as per ecotypes and genetic diversity (Vir 2007). It is therefore necessary to identify ecotypes with higher content of AZ and other limonoids. At present, such ecotypes are available for neem (Rangaswamy and Parmar 1995; Senguttuvan et al. 2005) and *Melia azedarach* (Kaur et al. 2005). Breeding to develop such ecotypes if undertaken in near future, they can be recommended for planting in forest areas. Further, synthesized commercial products and traditional preparations from each geographical area must be patented. This aspect of legal protection to plant products/natural pesticides is hardly thought of by the local business firms, farmers' cooperatives and NGOs though it has worldwide significance (Gahukar 2003).

(9) Infestation of the teak defoliators has been regularly reported from Chhatisgarh state and North East region in India. A regional/zonal network when established would provide information on pest distribution, population fluctuation and tree damages and would facilitate planning of proper measures well in advance.

(10) When a mixture of plant product and synthetic pesticide is sprayed, the bioefficacy is better in term of pest mortality due to synergistic effect, viz., Nimbecidine® + quinalphos as antifeedant, insect growth regulator and pesticidal (Ramarethinam et al. 2002 b); NO + endosulfan as pesticidal (Sundararaj 1997). In these mixtures, dose of synthetic pesticide is halved and therefore reduction in application cost is possible.

(11) The survival of natural enemies must be safeguarded in forest zones. This is possible by replacing chemicals with plant products. For example, two coccinellid beetles, *Illeis cincta* F., *Illeis bistigmosa* Mulsant, feed on spores of fungus *Phyllactinia corylea* (Pers.) that cause powdery mildew on mulberry. In the plantation, when sprays of NO (2%) and karathane 19.5WP (0.2%) were applied against pests, neither the survival nor augmentation of these predators was disturbed due to neem oil (Krishnakumar and Maheshwari 2004). This aspect is important in integrated pest management particularly from the point of view of conservation of natural enemies of insect pests including birds that live in and eat fruits of forest trees. Further, volatiles emitted by plants play an

important role in augmentation and conservation of natural enemies (Degenhardt et al. 2003). If mechanism for inducing forest plants to emit attractants is known, a reasonable population of potential beneficials can be maintained in the ecosystem and natural pest control would be possible. These studies should be extended to include honey bees, pollinators and entomopathogens.

(12) In certain instances, plant products gave pest mortality equal to or higher than synthetic pesticides. For example, a mixture of NO (2%) + formulation of *Bacillus thuringiensis* subsp. *kurstaki* Berl. (1 $kg \cdot ha^{-1}$) and monocrotophos 36WSC (0.045%) against larvae of *Pempelia morosalis* in jatropha plantations (Ambika et al. 2007); NO (0.5%) versus monocrotophos 36WSC (0.05%) or endosulfan 35EC (0.07%) against *Acaudaleyrodes rachipora* on acacia (Sundararaj et al. 1995); Neemark® (5 $mL \cdot L^{-1}$) versus endosulfan 35EC (0.07%), methyl parathion 50EC (0.05%) or malathion 50EC (0.05%) against larvae of *Plecoptera reflexa* on shisham (Jemla Naik et al. 1995).

(13) Foresters and planters need intensive training on organic production of wood that has export potential and may fetch higher price even in local markets (Saravanne et al. 2007). The termite-resistant teak genotypes are not easily available and chemicals are used for pest control.

(14) In most of the forest ecosystems, the pest management strategy comprising of cultural methods, pest tolerant genotypes and biological control agents, is being implemented (Singh et al., 2004). The plant products can easily be included in the present plant protection schedules. Plant products can be effectively used on trees and stored wood. This would reduce the pest control cost. The raw (plant) material is easily available in villages. The extension services of all concerned partners should work on this line so as to convince the growers of the adoption of integrated strategy.

(15) Although more interventions are needed for certain pests and diseases for evolving management strategy, plant products can be tested on experimental basis. This list includes *Catopsilia crocale* Cramer, *Catopsilla scrabrator, Tonica niviferana, Hoplocerabyx spinicornis*, blister bark disease on *Casuarina equisetifolia* caused by *Subramniaspora vesiculosa*, root and heart rot on acacia caused by *Ganoderma* spp., *Phellinus* sp., root rot (*Phellinus gilvus, Coriolopsis sanguinaria*) and rust (*Uredo sissoo*) on shisham trees.

(16) Amongst forest trees in temperate climate, only poplar tree has been reported as victim of pest attack in India. Plant products tested in temperate countries may be tried against important pests. For example, NSKE (3%) against *Fenusa pusilla* Lepeletier (Larew et al. 1987; Marion et al. 1990); Margosan-O against *Chroristoneura fumiferana* (Clemens) (Thomas et al. 1992); AZ against *Macalla thyrsisalis* Wlk. (Howard 1990), *Morimus funerues* L. (Frusic et al. 1988) and *Pityogenes chalcographus* L. on several forest trees (Wulf and Schneidermann 1990).

Conclusion

Pest and disease management in forestry should receive more attention of foresters and planters and plant products are to be recommended for protecting forests. These products are developed from indigenous plants, easily degrade and residual toxicity is eliminated; danger to natural enemies and non-target organisms is avoided; effectiveness is either equal or greater than synthetic pesticides. Thus, prospects of plant products seem to be immense and profit making. However, government institutions, NGOs, planters' associations, wood merchants/traders and social workers should consider plant products as one of the appropriate alternative to hazardous pesticides for effective management of pests and diseases.

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